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14. ABSTRACT
The Digital Mapping, Charting & Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has been developing the distribution of geographic data over the Web through its Geospatial Information Database. While this work has primarily included digital mapping information from a variety of formats, DMAP has also been working on 3D synthetic environment data delivery. This chapter describes DMAP's work to provide a three-dimensional representation of geographic data. We provide an overview of the data structures used to reconstruct 3D synthetic environments and to store full 3D topology. We also describe a prototype that supplements traditional 2D digital-mapping output with a 3D interactive synthetic environment.

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synthetic envoronment, 3d-gis, vrml, vpf extension, vpf+, non-manifold, 3d topology

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Chapter #

Adding the Third Dimension to Digital Mapping

Subtitle

Miyi Chung, Dr. Roy Ladner, Ruth Wilson, John Breckenridge, Kevin B. Shaw
Naval Research Laboratory

Key words: Synthetic environment, 3D-GIS, VRML, VPF extension, VPF+, non-manifold, 3D topology

Abstract: The Digital Mapping, Charting & Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has been developing the distribution of geographic data over the Web through its Geospatial Information Database. While this work has primarily included digital mapping information from a variety of formats, DMAP has also been working on 3D synthetic environment data delivery. This chapter describes DMAP's work to provide a three-dimensional representation of geographic data. We provide an overview of the data structures used to reconstruct 3D synthetic environments and to store full 3D topology. We also describe a prototype that supplements traditional 2D digital-mapping output with a 3D interactive synthetic environment.

1. INTRODUCTION

With the increasing use of computers, mapping has grown from paper charts and maps to digital format. The Digital Mapping, Charting and Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has been actively involved in this area through its Geospatial Information Database (GIDB). The GIDB is an object-oriented, CORBA compliant spatial database that supports remote access and analysis of spatial data via a Java Applet over the Internet [GIDB]. The digital maps produced by the GIDB like their paper counterparts, however, omit much geometric and visual information available in a three-dimensional synthetic environment (3D SE). In contrast to the 2D digital map, the 3D SE also provides a virtual

world that the user can explore. Our synthetic environment work has focused on developing a 3D-application prototype that would assist the U.S. Marine Corps with mission preparation and rehearsal and also provide onsite awareness during actual field operations in urban areas. Because these operations require practice in physically entering and searching both entire towns and individual buildings, we designed a prototype that supplements the more traditional 2D digital-mapping output with a 3D interactive synthetic environment.

Our prototype uses an extension of the National Imagery and Mapping Agency's (NIMA) Vector Product Format (VPF) [VPF 96], known as VPF+ [Abdelguerfi 98]. The representational scheme of VPF+ includes topologic information in addition to geometric information. The geometric information allows for detailed 3D modeling. The topologic information encompasses the adjacencies involved in 3D manifold and non-manifold objects, and is described using a new, extended Winged-Edge data structure. This data structure is referred to as "Non-Manifold 3D Winged-Edge Topology," and it adds a new level of topology to VPF called Level 4 Full 3D Topology (Level 4). The inclusion of explicit topological information about three-dimensional relationships in the environment means that many 3D spatial relationships do not have to be derived at run-time, a factor that should be significant to many applications.

2. THE VPF+ DATA STRUCTURE

NIMA has promulgated VPF as a government standard for large geographic databases. Some of NIMA's VPF products, for example, include Urban Vector Map, Digital Nautical Chart, Tactical Terrain Data and Digital Topographic Data. These databases are numerous. VPF+ was designed as a superset of the VPF specification to afford VPF users a smooth transition to 3D within the traditional VPF paradigm.

2.1 VPF+ Primitives

The data structure relationships of VPF+ are summarized in the object model shown in Figure 1. References to geometry are omitted for clarity. There are five main VPF+ primitives found in Level 4 topology:

- *Entity node* – used to represent isolated features.
- *Connected node* – used as endpoints to define edges.
- *Edge* – an arc used to represent linear features or borders of faces.
- *Face* – a two-dimensional primitive used to represent a facet of a three-dimensional object such as the wall of a building.

– *Eface* – describes a use of a face by an edge.

Unlike the topology of traditional VPF, Level 4 topology does not require a fixed number of faces to be incident to an edge. The *Eface* is a new primitive that is introduced to resolve some of the ensuing ambiguities. Efaces describe a use of a Face by an Edge and allow maintenance of the adjacency relationships between an Edge and zero, one, two or more Faces incident to an Edge. This is achieved in VPF+ by linking each edge to all faces connected along the edge through a circular linked list of efaces. Figure 2, for example, shows three faces incident to a single edge, three efaces and three "next" edges. Each eface, as shown in Figure 2, identifies the face it is associated with, the next eface in the list and the "next" edge about the face in relation to the edge common to the three faces. Efaces are also radially ordered in the linked list in a clockwise direction about the edge in order to make traversal from one face to the radially closest adjacent face a simple list operation.

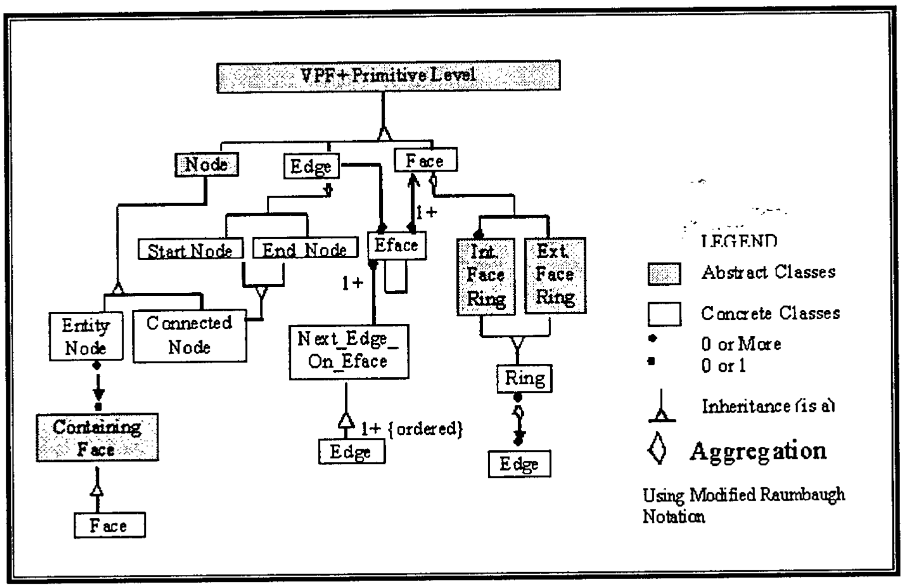

Figure 1. VPF+ Primitive Level Object Model

2.1.1 VPF Enhancements

In addition to the eface structure, VPF+ introduces several extensions to VPF consistent with non-manifold topology and 3D modeling. One extension is the Node-Edge relationship. VPF relates each Connected Node to exactly one Edge. VPF+ allows for non-manifold Nodes. This requires

that a Node point to one Edge in each object connected solely through the Node and to each dangling Edge (an edge that is adjacent to no face). This relationship allows for the retrieval of all Edges and all Faces in each object and the retrieval of all dangling Edges connected to the Node.

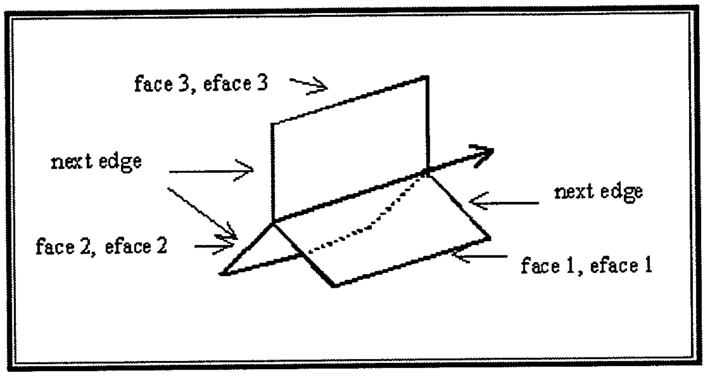

Figure 2. Relationship of a Shared Edge to its Faces, Efaces and Next Edge

Another extension is the absence of VPF's Universal Face in the non-manifold 3D topology. The "universe face" is defined in VPF as the unbounded region surrounding a coverage. A coverage in VPF is composed of features whose primitives maintain topological relationships according to one of the four levels of topology (Levels 0 through 3) found in VPF. The universal face is absent in Level 4 since it is a planar construct and Level 4 topology deals with 3D features.

A third extension provided by VPF+ is the presence of Two-Sided Faces. Faces are defined in VPF as purely planar regions. In VPF+ Faces may be one sided or two sided. A two sided Face, for example, might be used to represent the wall of a building with one side used for the outside of the building and the other side for the inside of the building. Feature attribute information would be used to render the two different surface textures and color. A one sided Face might then be used to represent the terrain surface.

Embedded faces are another extension offered by VPF+. That is, faces may be embedded within a 3D object. As an example, an embedded double-sided Face might divide a building into two floors. Other double-sided Faces might then divide each floor into separate rooms.

Another extension provided by VPF+ is Object Orientation. Orientation of the interior and exterior of 3D objects is organized in relation to the normal vector of Faces forming the surface boundary of closed objects. This allows for easy distinction between an object's interior and exterior.

VPF organizes spatial data into coverages of thematically consistent data that share a single coordinate system and scale and that are contained within

a specified spatial extent. Each coverage is then composed of features whose primitives maintain topological relationships according to one of the four levels of topology (Levels 0 through 3) found in VPF. VPF+ extends this with Level 4 topology, which supports a single, integrated, topologically consistent three-dimensional coverage of heterogeneous features. This environment can include objects generally associated with the terrain surface (buildings and roads for example). It can also include objects that are not attached to the terrain but are rather suspended above the terrain surface or below a water body's surface.

2.1.2 Non-Manifold Objects

Topology is significant to many applications. Modeling and simulation applications, for example, make use of dynamic, reasoning software models that utilize non-visual spatial information about the environment [USAS 98]. Non-manifold objects are commonplace in the real world and should also be readily found in 3D SEs. Explicitly maintaining non-manifold topology should eliminate the need to computationally derive many spatial relationships at run-time.

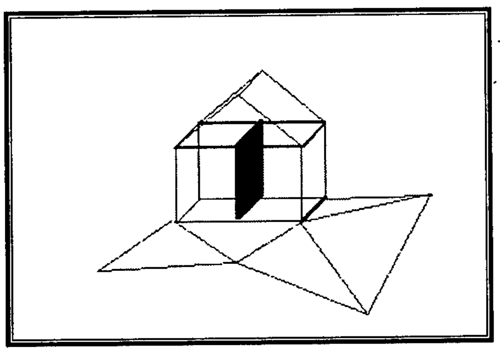

Figure 3. Non-Manifold Condition with Multiple Faces Incident at a Single Edge

Some examples of non-manifold objects are shown in Figures 3 through 5. Figure 3 gives an example of a building (shown in wireframe for clarity) with an interior face representing an interior wall and a portion of a terrain surface shown in wireframe. Each of the four edges defining the interior face is adjacent to exactly three faces - the interior face and two each for the faces forming the front and rear walls, ceiling and floor of the building. Additionally, each horizontal edge forming the baseline of the faces which makes up the exterior walls of the building is adjacent to three faces - one forming a terrain triangle, one representing the building's floor and one representing the building's exterior wall.

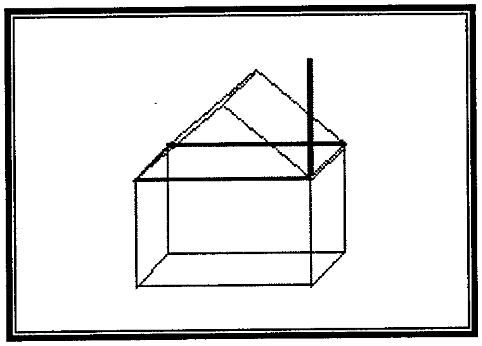

Figure 4. Non-Manifold Condition Consisting of Dangling Edge

Figure 4 shows another example of a non-manifold condition that may be found in a 3D SE. The wireframe building has an edge attached at the roof. The edge, which may represent an antenna, is a dangling non-manifold edge since it is adjacent to no face.

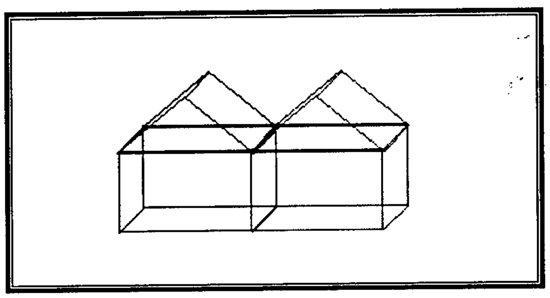

Figure 5. Two Buildings Sharing a Face With a Non-Manifold Condition at the Shared Face

A final example of a non-manifold condition that may be found in a 3D SE is shown in Figure 5. There, two buildings are shown sharing a common face. At least one non-manifold condition is identified by the red edge, which is related to five faces - the shared face forming the common wall, two ceiling faces and two roof faces.

3. THE PROTOTYPE

The prototype consists of a Web-based virtual reality application for a Military Operations in Urban Terrain (MOUT) site at Camp Lejeune, North Carolina. The MOUT site consists of a small city built by the U.S. Marine Corps for the purpose of training in an urban setting. This application employs a Web browser to select a user-defined extent of terrain and known features existing within that extent. The database is queried and a 2D map is produced alongside a 3D synthetic environment generated using the Virtual Reality Modeling Language (VRML). A Web-browser plug-in such as Cosmo Player provides interactive 3D functionality such as the capability for the user to move through and interact with the SE.

We created a 3D synthetic environment for this prototype that replicates its real-world counterpart by including natural features as well as man-made structures such as buildings, roads, and streetlights. The elevation data for the MOUT site is Digital Terrain Elevation Data (DTED), Level 5, with one-meter resolution. We used ArcInfo to create a Triangulated Irregular Network (TIN) of the elevation data. The original terrain elevation data contained over 90,000 elevation points for an area of only approximately 600 meters square. TINning reduced the total elevation points to approximately 400, greatly improving performance. The remaining elevation points were considered adequate to approximate the terrain since this geographic area is known to be relatively flat. Lines forming the buildings' footprints were used as constraints to guarantee a uniformly flat terrain under each of the buildings. As a final terrain data preprocessing step, ArcInfo was used to convert the TIN into an ArcInfo Net File containing primitive data for all nodes, edges and faces in the terrain. Primitives defining 3D buildings were obtained by digitizing "flat" building plans into three dimensions. Roads, previously existing only as centerlines, were also widened to their real-world width. VPF+ tables were then populated with this data.

Since the construction drawings of the buildings were readily available, we were able to create highly accurate interiors and exteriors of the buildings in a short period of time. We did this by using an on-screen digitizer and JPEG's of the construction drawings. The digitizer allowed us to capture the detailed geometry of the buildings along with additional information needed to build VPF+ Level 4 topology. This process required approximately two hours on the average to digitize a two-story building including all interior rooms, roof structure and exterior façade.

We maximized the user's experience within this synthetic environment by providing for movement and interaction consistent with the types of interactions expected of Marines during anticipated operations. For

example, users can walk or fly across terrain, and they can enter buildings through doorways or climb in through open windows. The synthetic buildings conform to their real-world floor plans, allowing direct line of sight into and out of buildings through open doorways and windows. Once inside a building, users can enter doorways to walk through interior rooms or climb stairs to access different floors.

Figure 6 shows the user interface we developed for the prototype. The features, symbolically represented in the traditional manner on the digital map on the left, are reconstructed as an interactive 3D virtual world on the right. The 3D buildings have a real-world appearance, and the roads have real-world width. Other features such as streetlights and trees are placed according to their real-world position and are made to resemble their real-world counterparts.

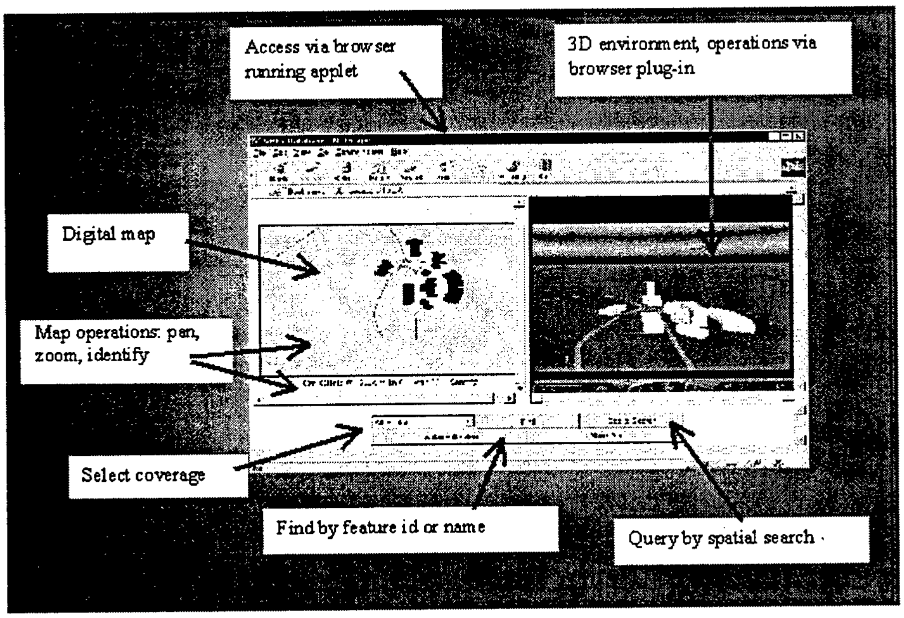

Figure 6. Prototype Mapping-3D Interface

Database querying is provided via *spatial search*, *find*, and *identify* functions. *Spatial search* allows the user to execute a simple 2D spatial query by defining a search distance and using the mouse to click on a point on the map. The search queries the database to identify features within the user-defined distance of the selected point. It then highlights the features it identifies on the map. The interface also triggers the database to produce the same features in full 3D. In contrast to *spatial search*, the user can apply the *find* function to locate a specific feature by name or ID number. The user

input queries the database, and then it highlights the located feature on the map. The user then has the option of rendering only the identified feature in full 3D. The *identify* function is the visual interface counterpart to *find*. The user selects the *identify* radial button on the map display, then uses the mouse to click on one of the features. The system queries the database for the identification of the selected feature, then it highlights the feature and shows its name and identification on the map. As with the find function, the user has the option of rendering solely the identified feature in full 3D by pressing the Show 3D button.

Figures 7 through 9 show views of some of the buildings, roads, and point features in the prototyped world. The system intentionally renders doorways and windows as open spaces because the environment is intended for field operations requiring rapid entry and exit of buildings. The light-blue interior walls visible in Figures 7 and 9 appear in a contrasting color to easily distinguish them from the building's boundary walls. Each of these views is accessible by navigating through the 3D SE within the browser interface shown in Figure 6.

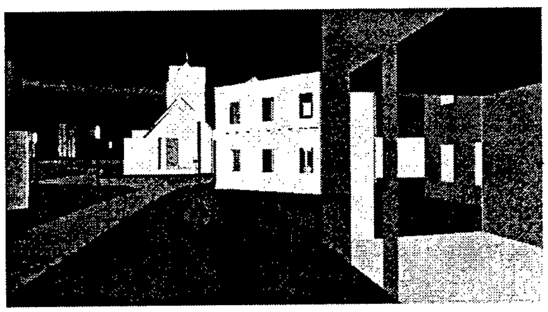

Figure 7. From Left, View of Church, Bank and Embassy Buildings at the Camp LeJeune MOUT Facility

Figure 8. View Across the Townsquare at the Camp LeJeune MOUT Facility

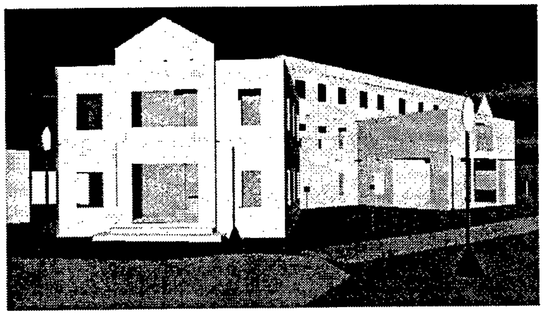

Figure 9. View of Bank and Embassy Building from the Townsquare at the Camp LeJeune MOUT Facility

4. NRL'S GIDB

NRL developed the GIDB through a project funded by the Defense Modeling and Simulation Office (DMSO) and the National Imagery and Mapping Agency (NIMA) to produce a prototype object-oriented (OO) database using the Digital Nautical Chart (DNC), one of NIMA's VPF products. VPF represents geographic features, along with their spatial and non-spatial attributes, through the use of relational tables. The GIDB was designed as object-oriented (OO). This OO design provided a means of addressing some of the issues that that accompany traditional VPF: topological support among coverages, non-duplication of features among coverages, improved data update, and increased access speed.

The GIDB has grown to support multiple VPF products (such as NIMA's Urban Vector Map database), raster imagery, shape file format, video clips, audio clips, temporal data and industry standards such as TIFF, GIF, and JPEG. GIDB users interested in a given area of interest can obtain, over the Web, a digital map supplemented with such diverse data.

The underlying motivation for having an Internet-based Java client access the OO database is to improve access to NIMA data. Currently, users of NIMA data must first obtain the data on CD-ROM or other storage media and then must also have resident on their own computer systems software to view the data. However, given NIMA's role as the primary geographic data distributor for the Department of Defense, it is clear that electronic dissemination and remote updating of NIMA's digital products is highly desirable. The GIDB allows a user with a Java-enabled web browser, such as Netscape, to access the database over the Internet and display mapping data available for a given area of interest. Remote data update by privileged users is also possible.

Other features provided by the GIDB include:

- Spatial query - topologic, geometric and attribute-constrained.
- Network access with optimized performance by the server responding only to the specified request from the user.
- Local dynamic updating and modification at the feature or object level.
- Real-time updates from the data provider, such as NIMA.
- Export to VPF relational format.

The user interface into the GIDB is shown in Figure 10. It consists of a Java applet running inside a Netscape Web browser. The user can select from a list of pre-defined areas of interest or choose an area of interest by moving the red box over the world map, as shown in Figure 10. The interface allows the user to chose from databases, libraries and coverages for a given region, to more fully refine the area of interest, to query the database and to merge data from different libraries and databases. The result of selecting a 16 by 20 kilometer region surrounding the U.S. Corps of Engineers Field Research Facility at Duck, North Carolina shown in Figure 11. The interface also provides a "live" vector-based map. That is, after the map showing the features for a given area of interest is displayed the user can change the color of feature classes to make them more easily distinguishable and features can be directly queried for attributes without further interaction with the database. The interface also allows the user to add additional features, even from different databases, to the currently displayed map.

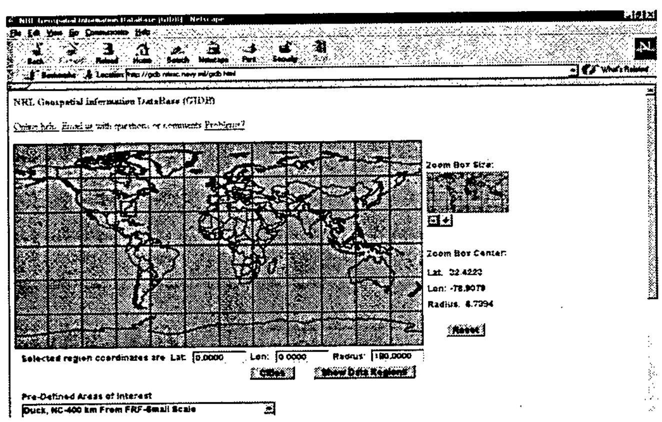

Figure 10. The GIDB User Interface

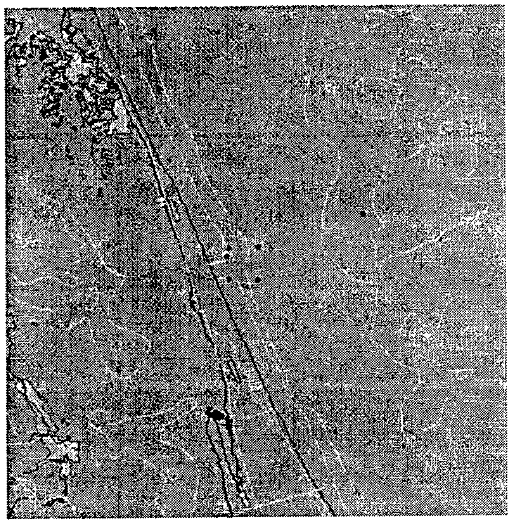

Figure 11. Sample GIDB Mapping Display

The U.S. Marine Corps has used the GIDB in two operations: Urban Warrior in 1999 and Millennium Dragon in 2000. In addition, the U.S. Navy is evaluating the GIDB for use on-board its ships. The GIDB's ability to integrate spatial and temporal data was also demonstrated in NIMA's Characterization of the Dynamic Littoral Zone project in 1999.

5. CONCLUSION

Our prototype demonstrated the effectiveness of supplementing traditional digital mapping output with a three-dimensional synthetic environment in a Web-based approach. The VPF+ design allowed for a smooth integration of the VPF+ 3D data with traditional VPF data into a common database. VRML proved to be a reasonable choice for viewing the 3D synthetic environment over the Web. Since VPF+ is an extension of NIMA's traditional VPF specification, incorporation of VPF+ into DMAP's GIDB should proceed relatively smoothly. Integration of our 3D work with the GIDB will allow users access to digital maps supplemented, when 3D data is available, with realistic, interactive 3D worlds via an Internet connection and a Web browser. Additionally, applications requiring 3D topological information should also benefit from VPF+ 3D non-manifold topology.

6. ACKNOWLEDGMENTS

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